Top Properties at the Tevatron

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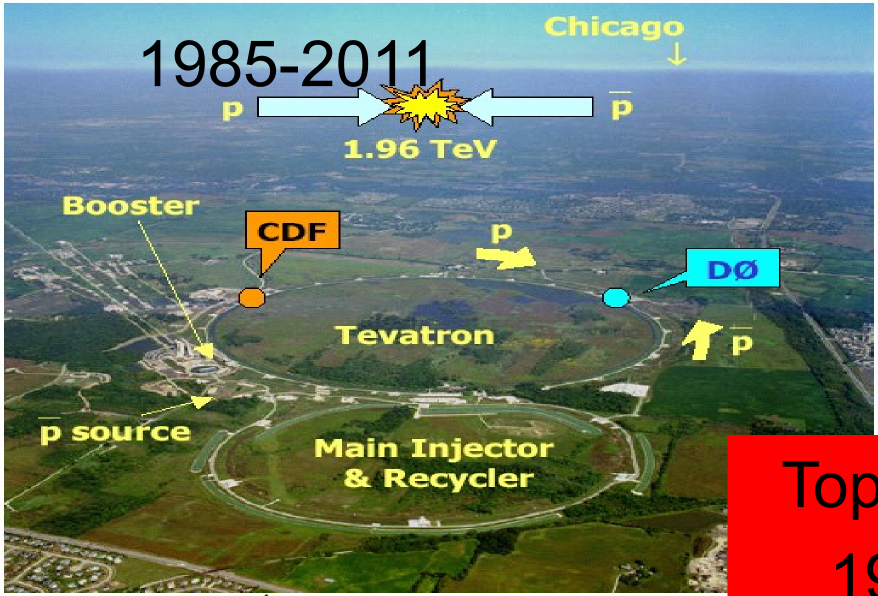
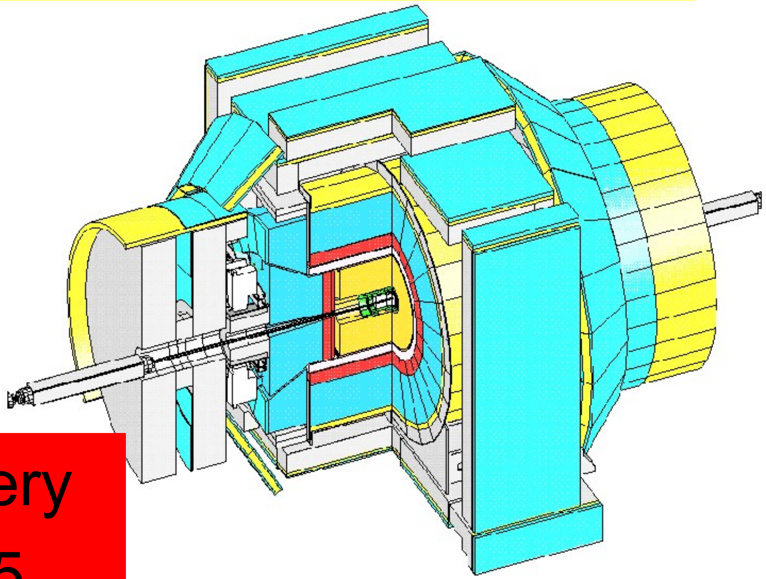
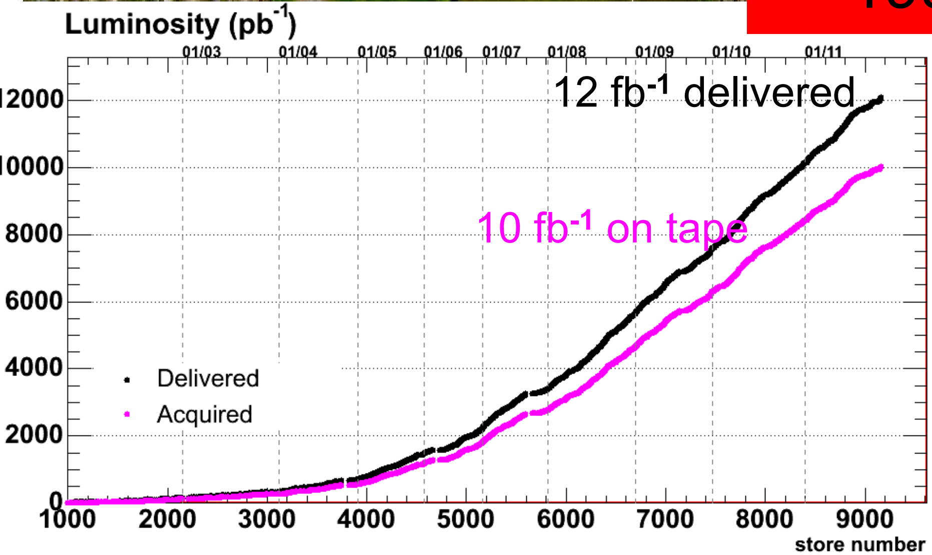
Tevatron, top..>20 yea

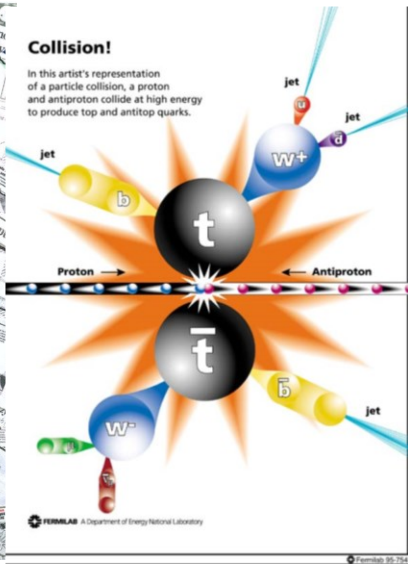




Top Discovery

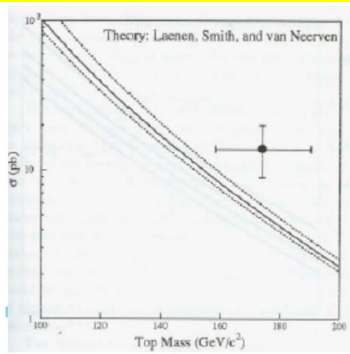
1994-1995

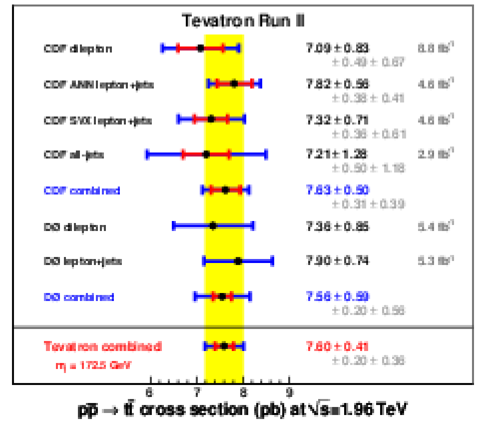


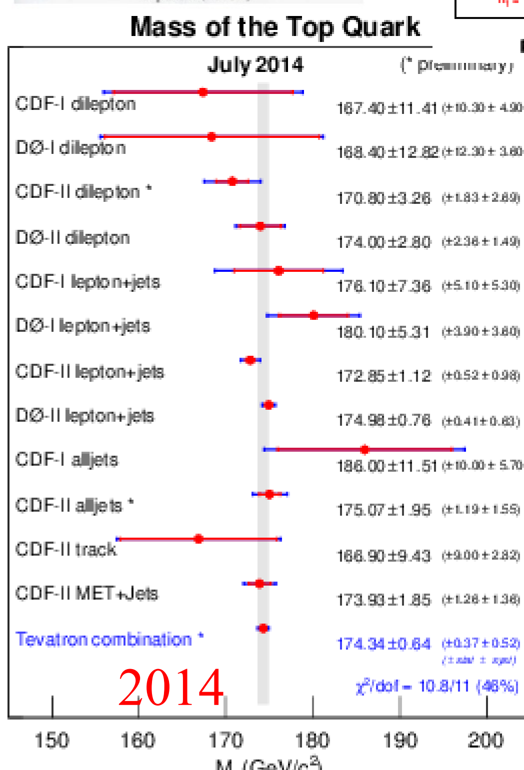


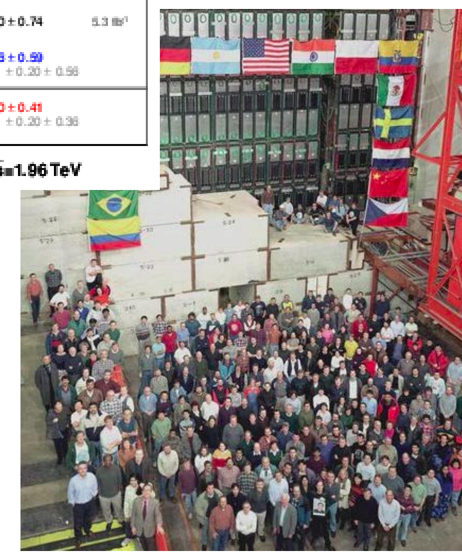
Top turns 20..

«...we will never see a mass peak..»

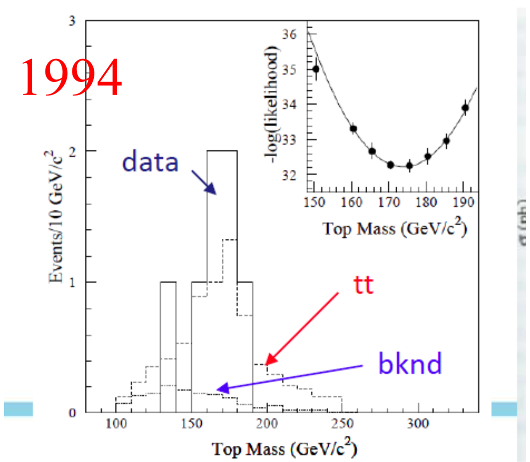




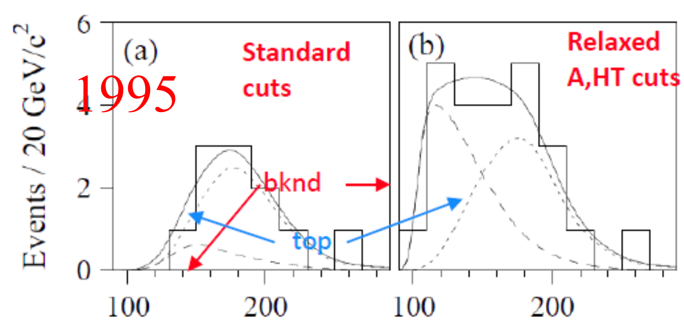




Mass fit from MC templates yields 174 ± 16 GeV



Reconstructed mass distribution



Why top is so interesting?

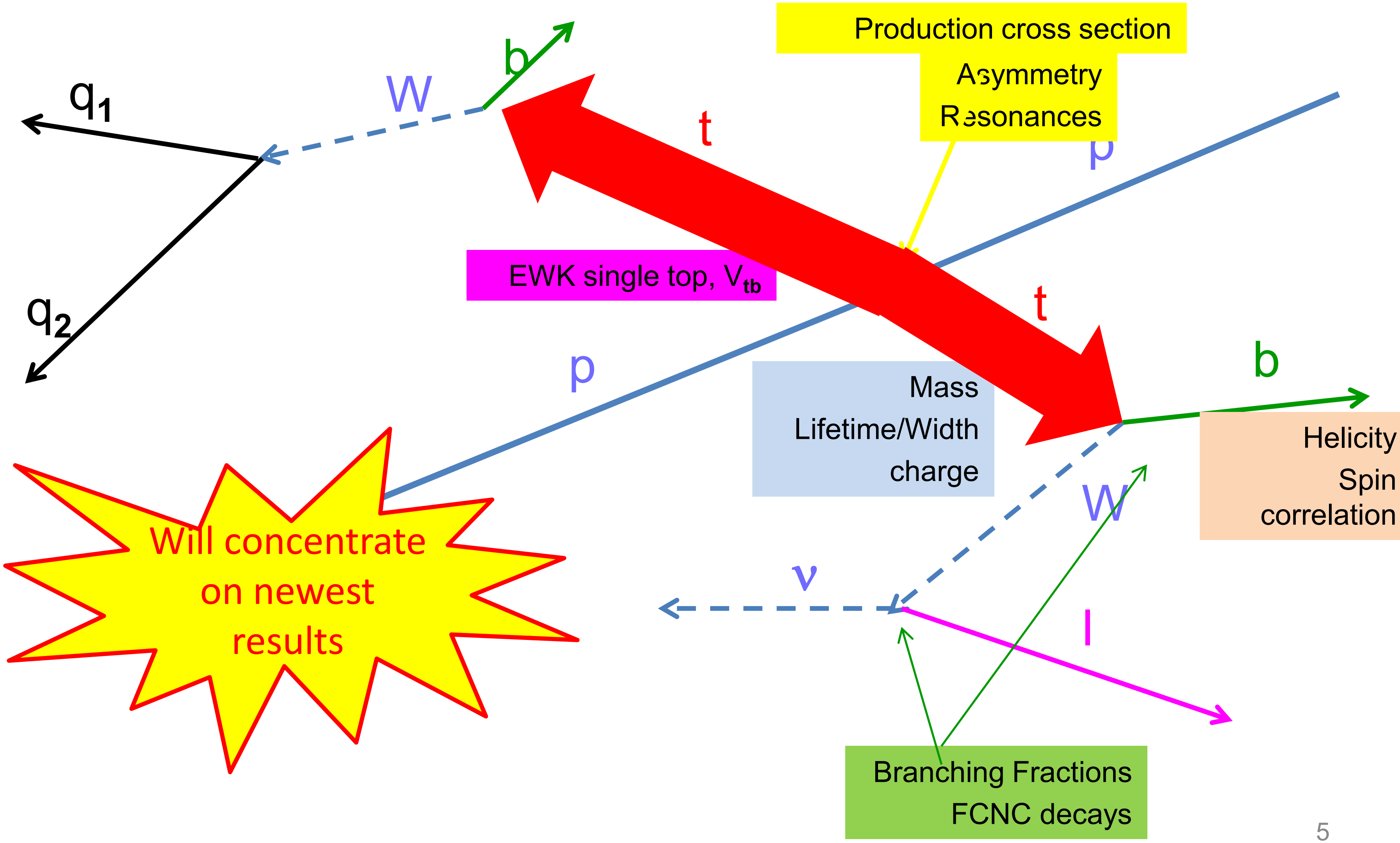
Heaviest quark known (~172.5 GeV/c^2)

- Decays before hadronization
  - No bound states («top mesons», «Upsilon-like»)
  - «direct» access to production and decay vertex
    - Couplings, CKM elements..
- Related to Higgs mass through loops
  - Precision measurement of M_W, M_{top}
    - Stability of our Universe…
- Yukawa coupling ~1
  - Anything special about top and its relation to EWSB?
    - Window to new physics?

Two different production mechanisms

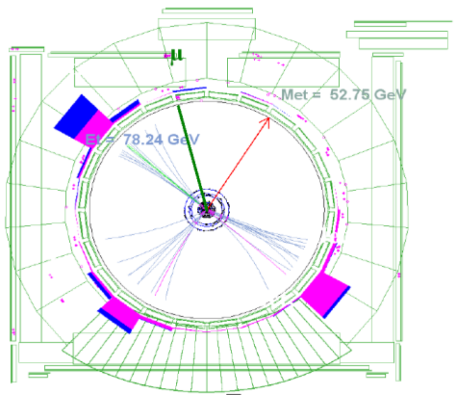
- Ewk processes
- Strong interactions

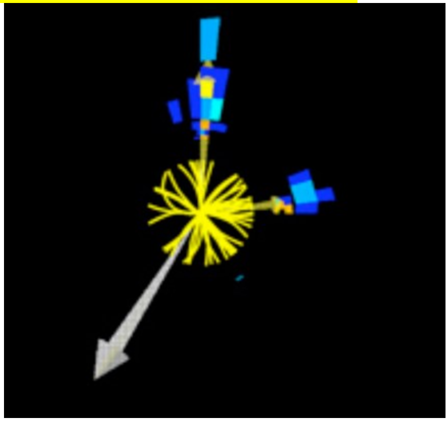
What can we study?

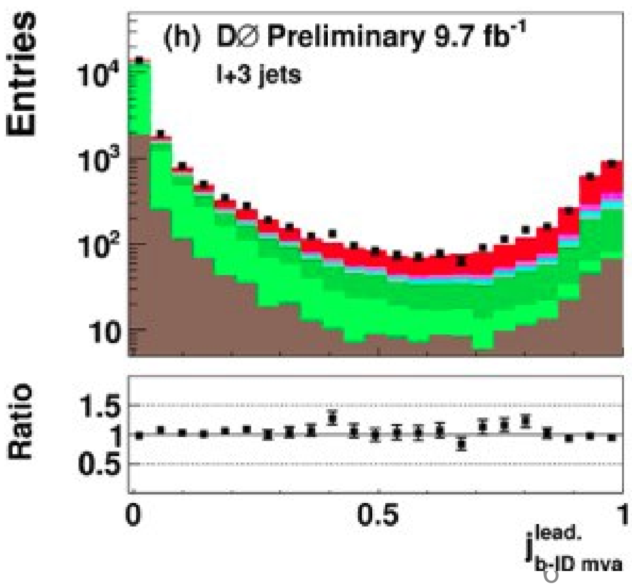


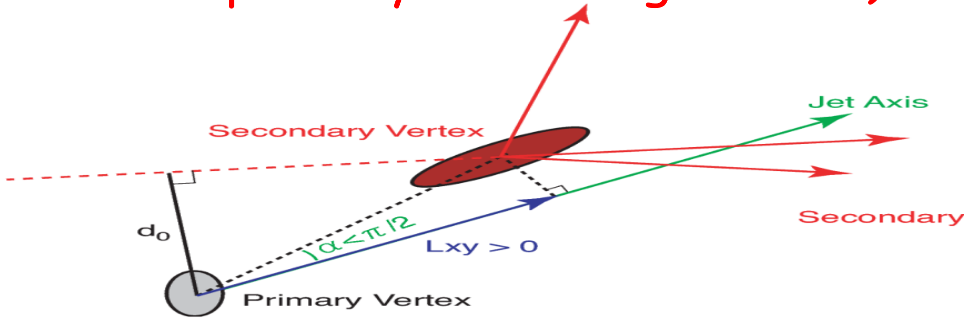
Tools: physics objects

- Hight Pt lepton (e or mu)
  - Isolated as coming from W
- 2 or ≥3 jets with large E_T
  - 20 GeV, $|\eta|<2.8$
  - Missing E_T (MET)
    - 25 GeV (CDF), 20/25 (D0)
- b-tagging
  - With a variety of tools (from tracks displaced from the primary to NN algorithms)





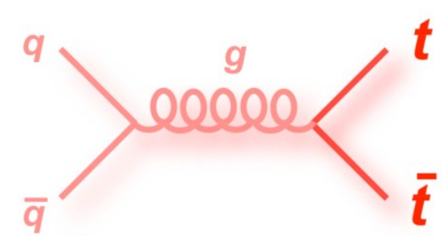


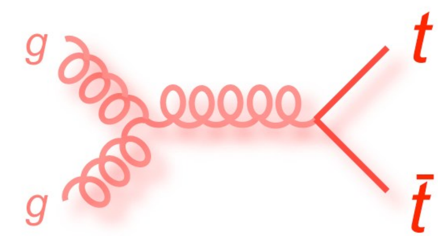


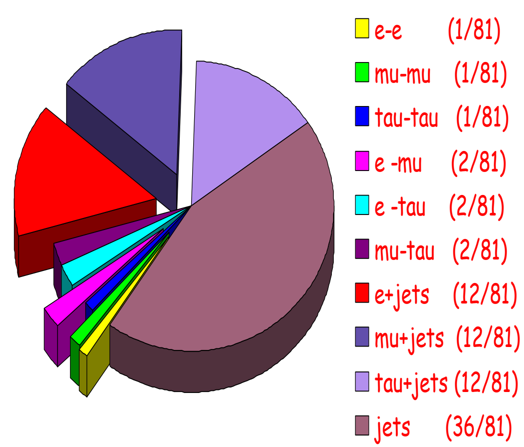
Production vertex

Top Pair production

- ~85 % through qqbar annihilation
- Calculated assuming BF (t→Wb)~100%
- Classified through W decay path
  - Dilepton (both Ws decay leptonically)
  - l+jets (in W decays into quarks)
  - All-hadronic (both Ws decay into quarks
    - We do not use W→τν decays
  - Dilepton (e,μ) ~5%: llννbb
  - l+jets (~30%): lν qqbb
  - All-hadronic (~45%):qqqqbb





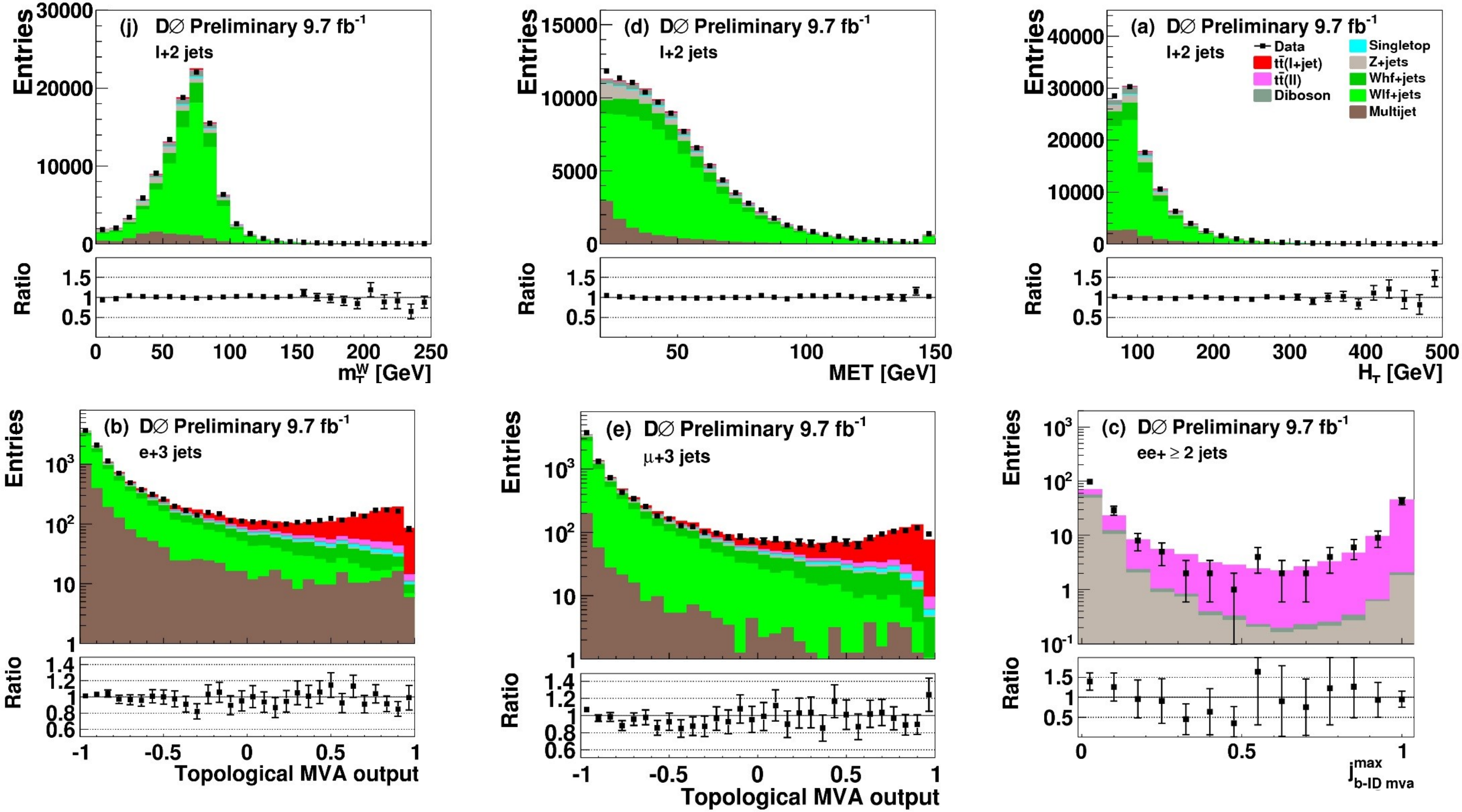


cross section: new

Updated σ_{tt} using full data-set in dilepton and l+jets samples:

- l+jets improved techinques:
  - Use events with n_{jet}=2,3,≥4
  - Include kinematics and b-tagging MVA in a BDT
    - Overall six subsamples, each one its own BDT
- Dilepton
  - divide into 4 subsamples, add MVA b-tag for leading jet
- Systematics included in fitting procedure
  - Nuisance parameters
  - Simultaneously explloints background-dominated region to constraint the fit
- Simultaneous fit to cross section in
  - l+jets
  - Dilepton
  - Combined

Some plots…



(j) DØ Preliminary 9.7 fb-1
l+2 jets
Entries
Ratio
m_T^W [GeV]
(d) DØ Preliminary 9.7 fb-1
l+2 jets
MET [GeV]
(a) DØ Preliminary 9.7 fb-1
l+2 jets
Data
tt̄(l+jet)
tt̄(ll)
Diboson
Singletop
Z+jets
Whf+jets
Wlf+jets
Multijet
H_T [GeV]
(b) DØ Preliminary 9.7 fb-1
e+3 jets
Topological MVA output
(e) DØ Preliminary 9.7 fb-1
μ+3 jets
Topological MVA output
(c) DØ Preliminary 9.7 fb-1
ee+ ≥ 2 jets
j^max_b-ID mva

Result(s)

- D0 updated:

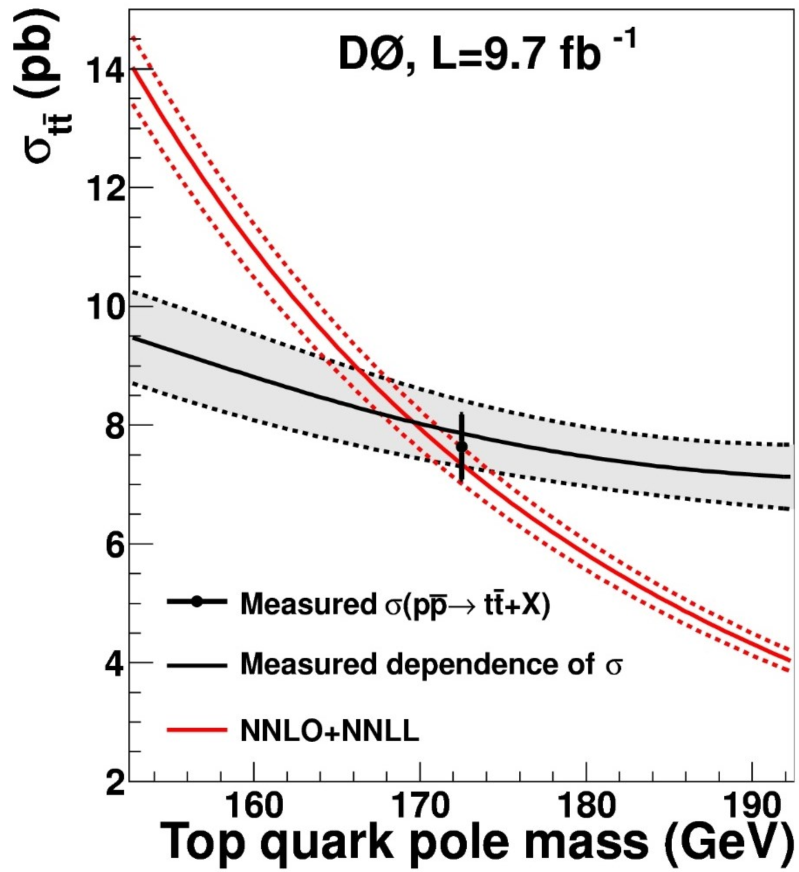
$$\sigma_{t\bar{t}} = 7.73 \pm 0.13(\text{stat}) \pm 0.55(\text{syst})\ \text{pb}$$

...then

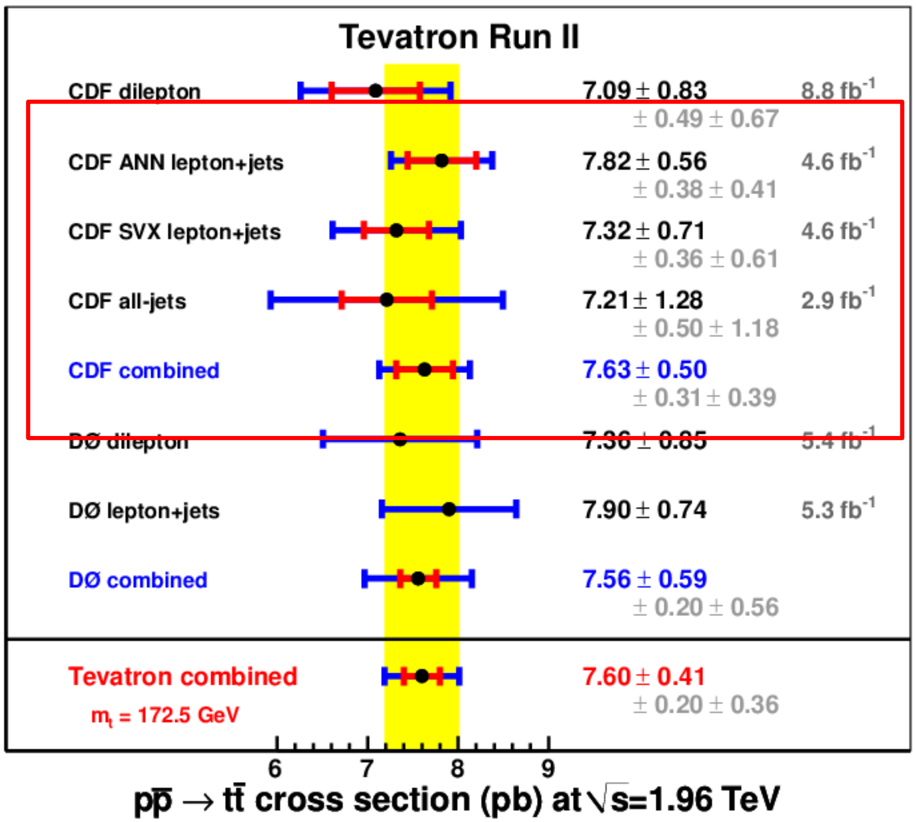
- Measure in MC the cross-section dependence from M_{top}, parametrize this dependence and plot
  - Top quark pole mass:

$$M_{top} = 169.5\ ^{+3.3}_{-3.4}\ \text{GeV}$$

More this afternoon: talk by Jiri Franc



σ_{tt} : summary



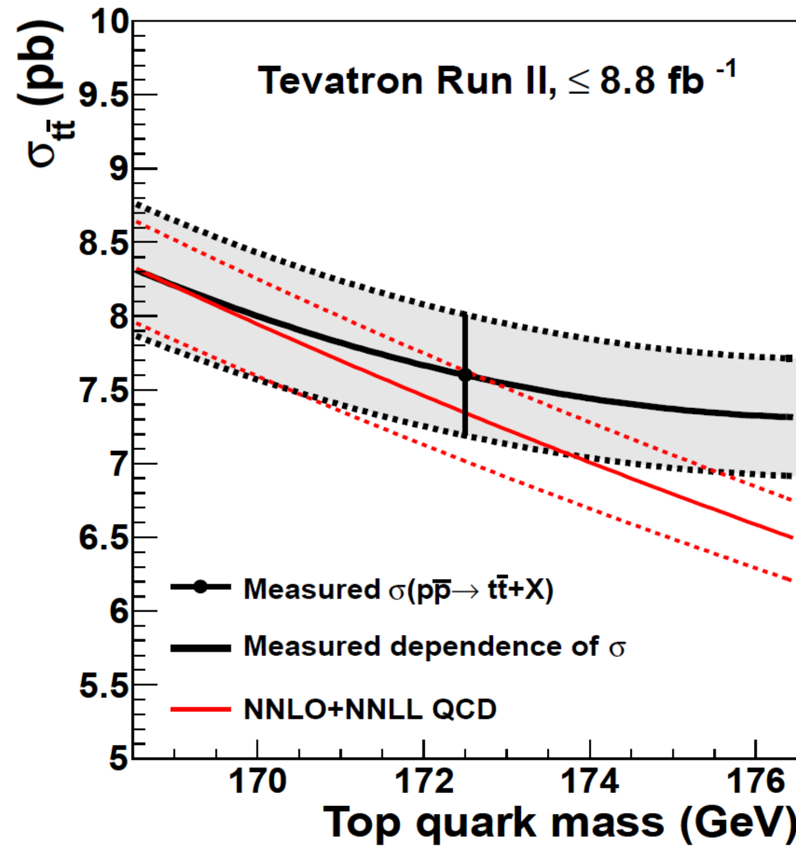
Theoretical prediction accuracy:4.4%

- $\sigma=7.35^{+0.11}_{-0.21}(scale)^{+0.17}_{-0.12}(PDF)$

CDF :7.63±0.5 pb (6.5%)

Tevatron: 7.60±0.41 pb

D0: 7.73±0.13±0.55 pb



CDF results contribute (to old) TeV combination by 60%, Only dilepton analysis uses the whole dataset

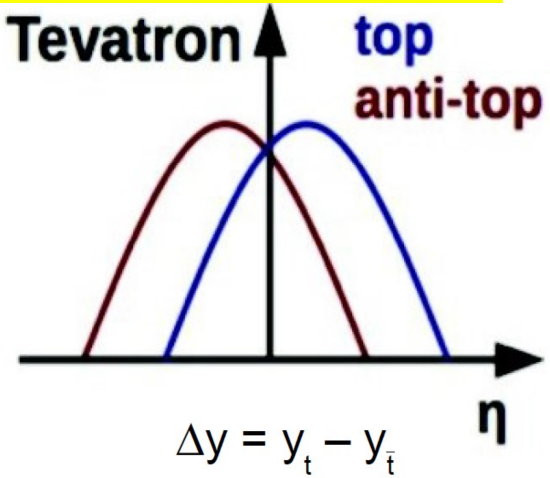
- **Does non include new D0 result**

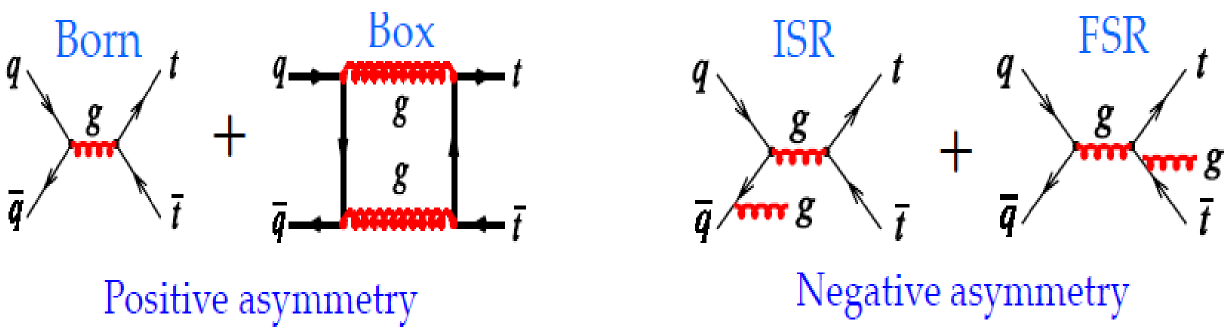
A_{FB} in ttbar events

A_{FB} is defined as $A_{FB} = \frac{N_{\Delta Y>0} - N_{\Delta Y<0}}{N_{\Delta Y>0} + N_{\Delta Y<0}}$

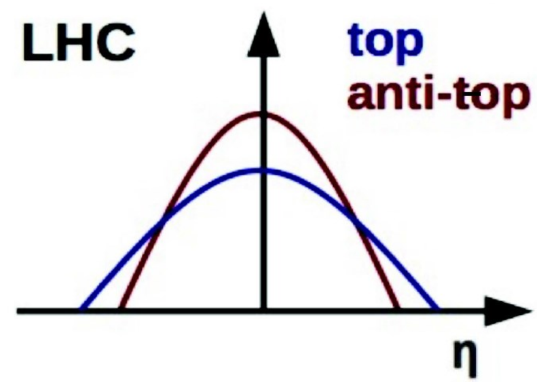
- Exploit symmetric proton-antiproton initial state
- Asymmetry is zero at leading order

- Inclusive A_{FB}=(10.0±0.6)%
  - N3LO (QCD+EWK): PRD 91, 071502(2015)





- Deviation from SM generated by
  - Axial Vector, Z' exchange, W' interaction
  - BSM scenarios should –however- be consistent with measured
    - σ_{tt}, $d\sigma/dM_{tt}$, LHC results
    - $d\sigma/d\cos\vartheta^*$



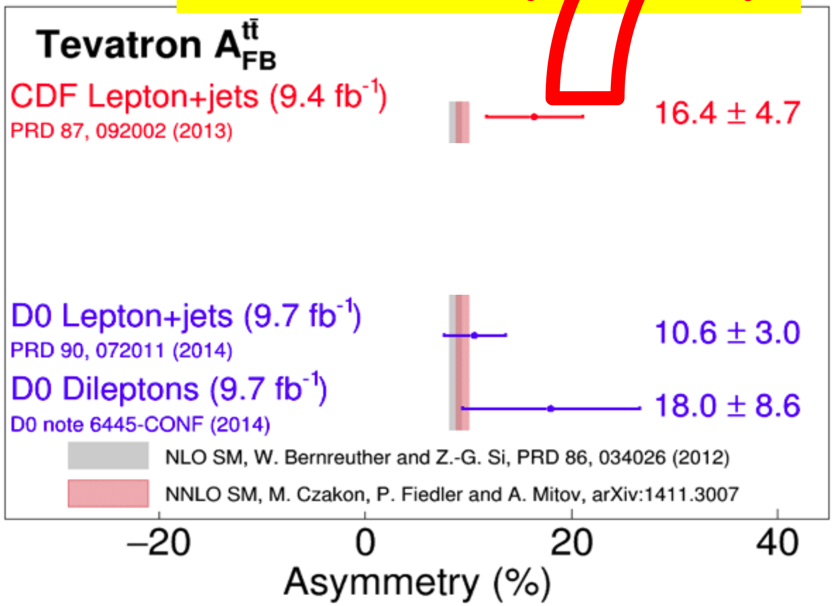
$$A_C = \frac{N(\Delta|y_t| > 0) - N(\Delta|y_t| < 0)}{N(\Delta|y_t| > 0) + N(\Delta|y_t| < 0)}$$

The AFB saga

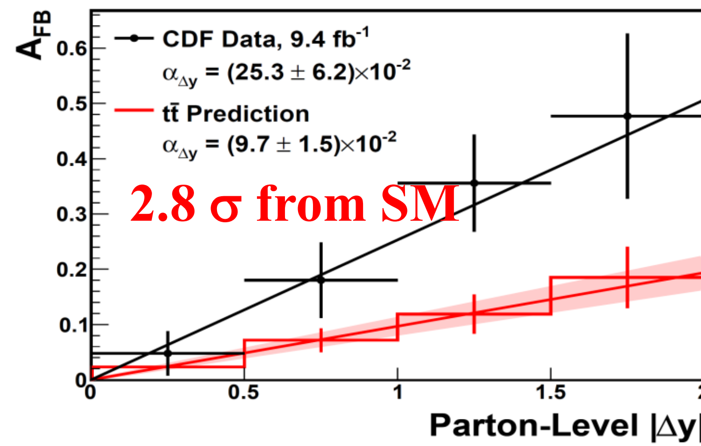
Is the AFB saga coming to a conclusion?

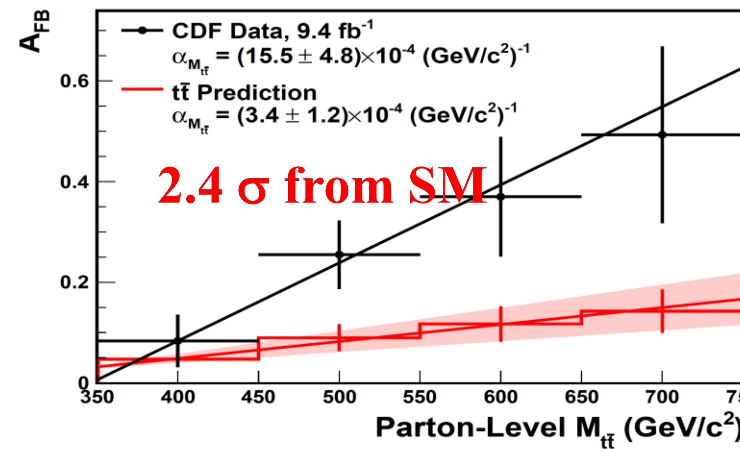
- Summary of previous episodes:

Inclusive asymmetry



A_{FB} vs Δy, M_{tt}



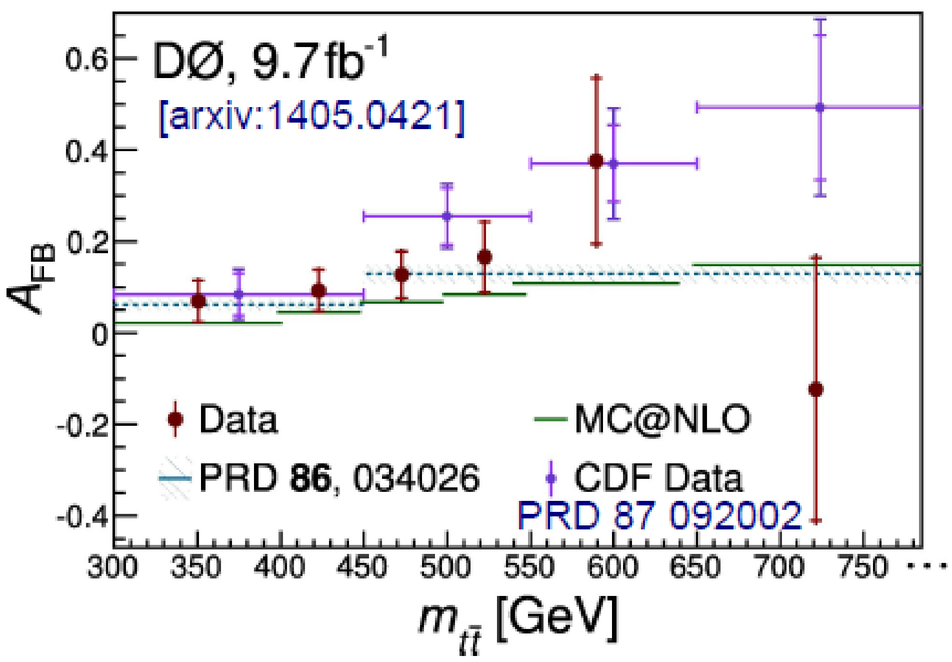


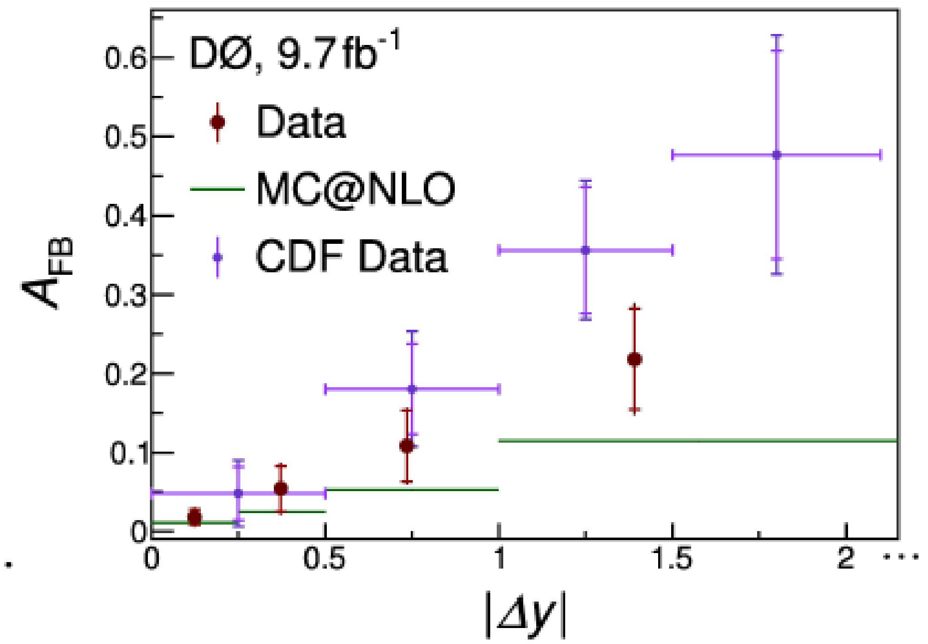
The largest difference from SM expectations in top-quark physics

SM or not SM?

D0 results are in agreement with SM predictions...

- But also with CDF data:



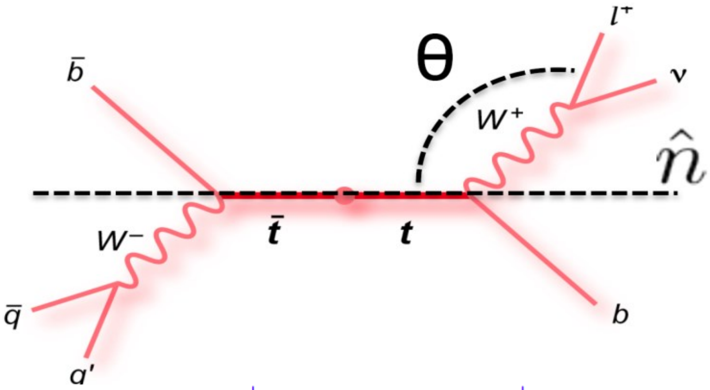


Full data set

D0 new measurement

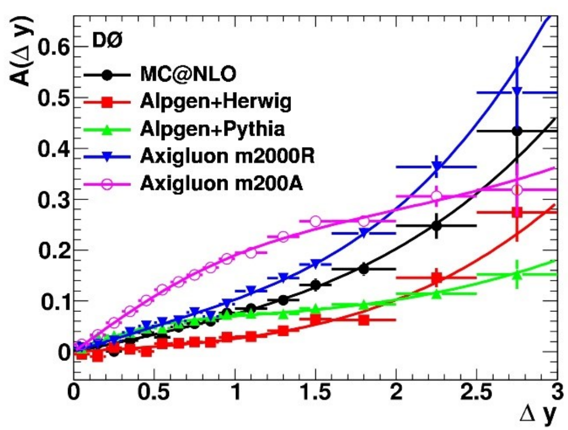
Dilepton channel, fit A_{FB} and polarization

- Polarization due to EWK contributions to production
- BSM can change both
- Use ME method



$$A_{\hat{n}}^{\ell^\pm} = \frac{N(\cos\theta^\pm > 0) - N(\cos\theta^\pm < 0)}{N(\cos\theta^\pm > 0) + N(\cos\theta^\pm < 0)}$$

$$\kappa P = A^{\ell^+} - A^{\ell^-}$$



Simultaneous measurement

$$A^{t\bar{t}} = (15.0 \pm 8.0)\%$$

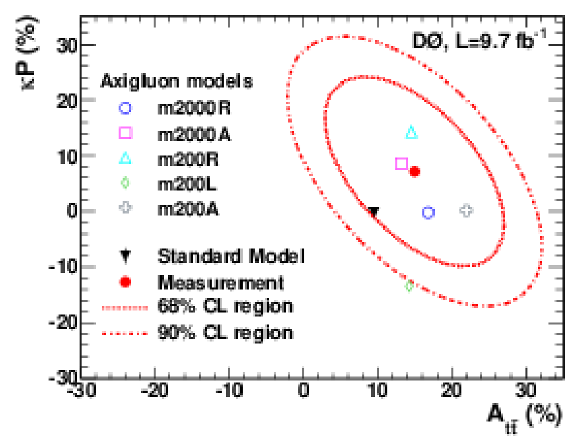
$$\kappa P = (7.2 \pm 11.3)\%$$

Assuming SM polarisation

$$A^{t\bar{t}} = (17.5 \pm 6.3)\%$$

Combination with l+jets channel

$$A^{t\bar{t}}_{\text{combined}} = (11.8 \pm 2.8)\%$$



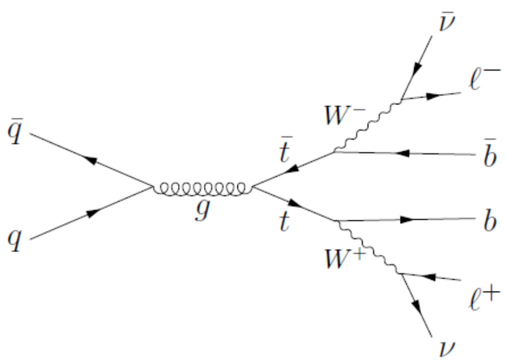
CDF: A_{FB} in dilepton

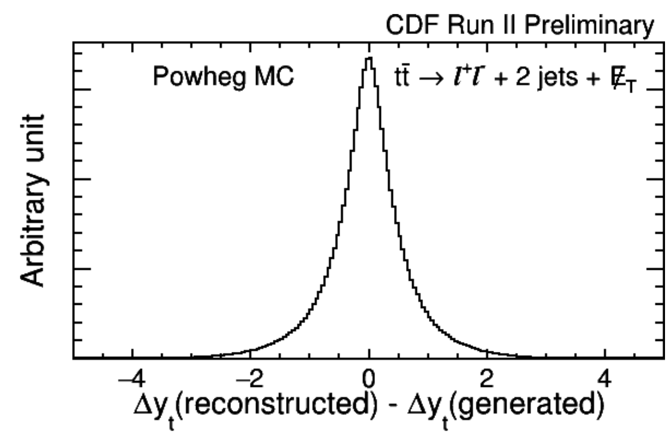
Full data set

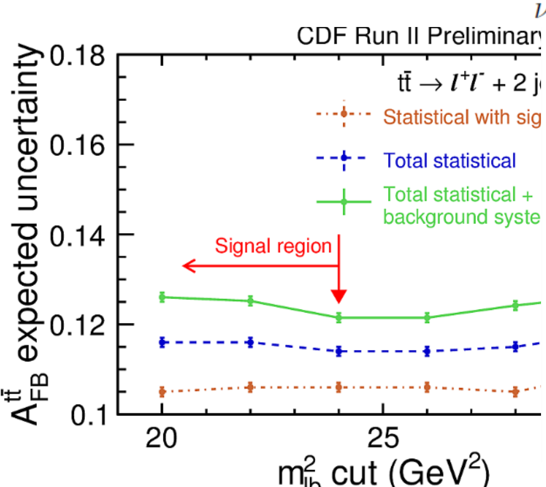
full data set in ll channel

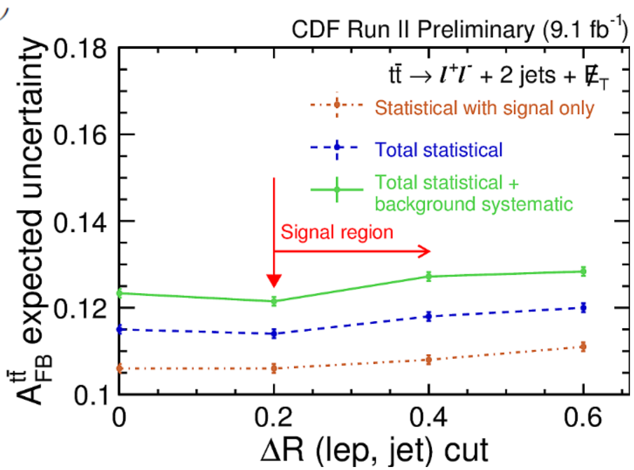
- top reconstruction optimized to reduce uncertainty in A_{FB}

$$A_{FB}^{t\bar{t}} = \frac{N(\Delta y_t > 0) - N(\Delta y_t < 0)}{N(\Delta y_t > 0) + N(\Delta y_t < 0)}$$





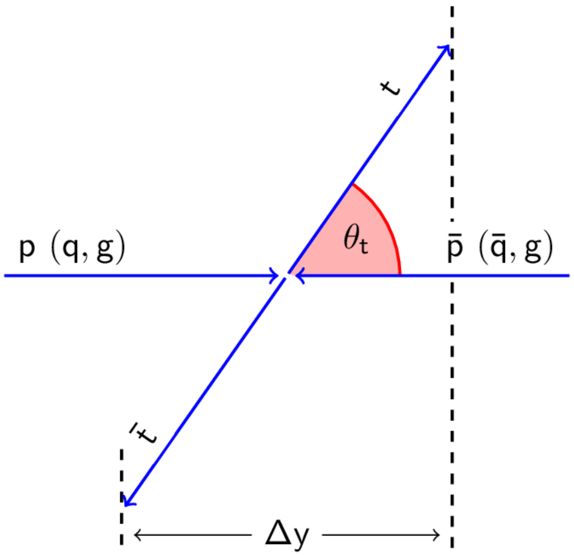




Use **measured dσ/dcosϑ*** to re-weight MC events

l+jet distribution dσ/dcosθ

CDF studied ϑ_t angle between proton and top quark direction in ttbar ref frame



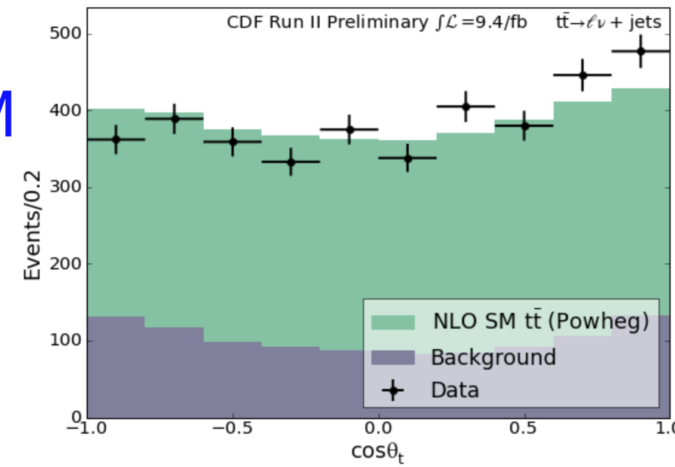
~Agreement with SM

Characterize using Legendre polinomials

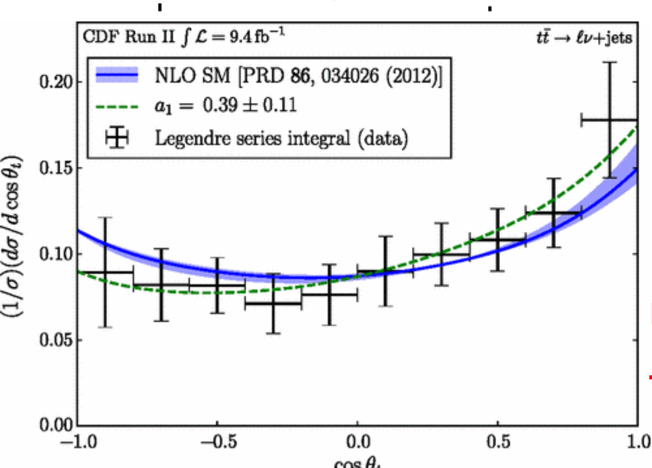
$$\frac{d\sigma}{d\cos\theta_t} = \sum_\ell a_\ell P_\ell(\cos\theta_t)$$

First moment shows tension with prediction

PRL **111**, 182002 (2013)



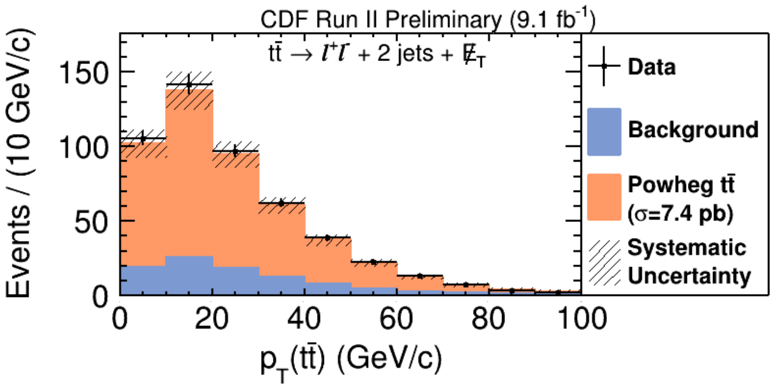
ℓ	a_ℓ (obs)	a_ℓ (pred)
1	0.40 ± 0.12	$0.15^{+0.066}_{-0.033}$
2	0.44 ± 0.25	$0.28^{+0.053}_{-0.030}$
3	0.11 ± 0.21	$0.030^{+0.014}_{-0.007}$
4	0.22 ± 0.28	$0.035^{+0.016}_{-0.008}$
5	0.11 ± 0.33	$0.0048^{+0.002}_{-0.001}$
6	0.24 ± 0.40	$0.0060^{+0.002}_{-0.003}$
7	-0.15 ± 0.48	$-0.0028^{+0.001}_{-0.001}$
8	0.16 ± 0.65	$-0.0019^{+0.0003}_{-0.0003}$

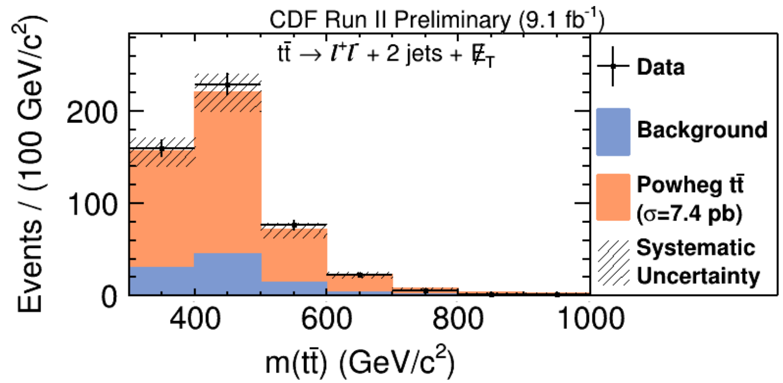


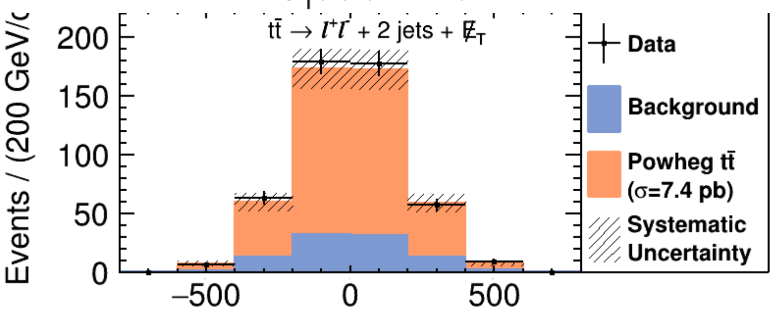
Use measured dσ/dcosϑ*

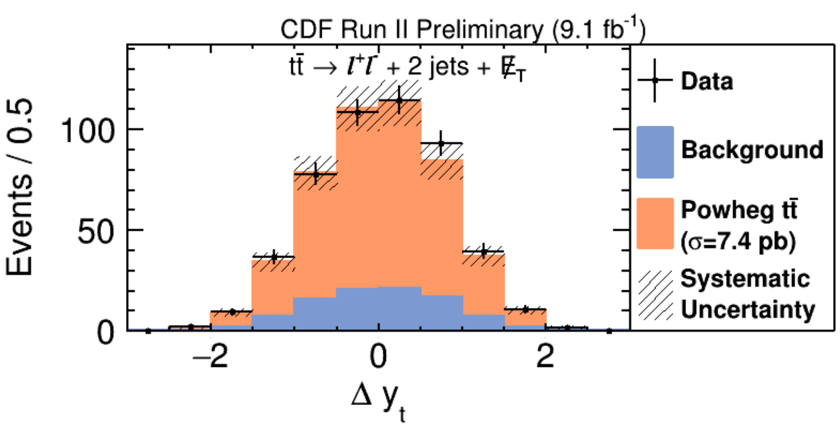
To re-weight MC events

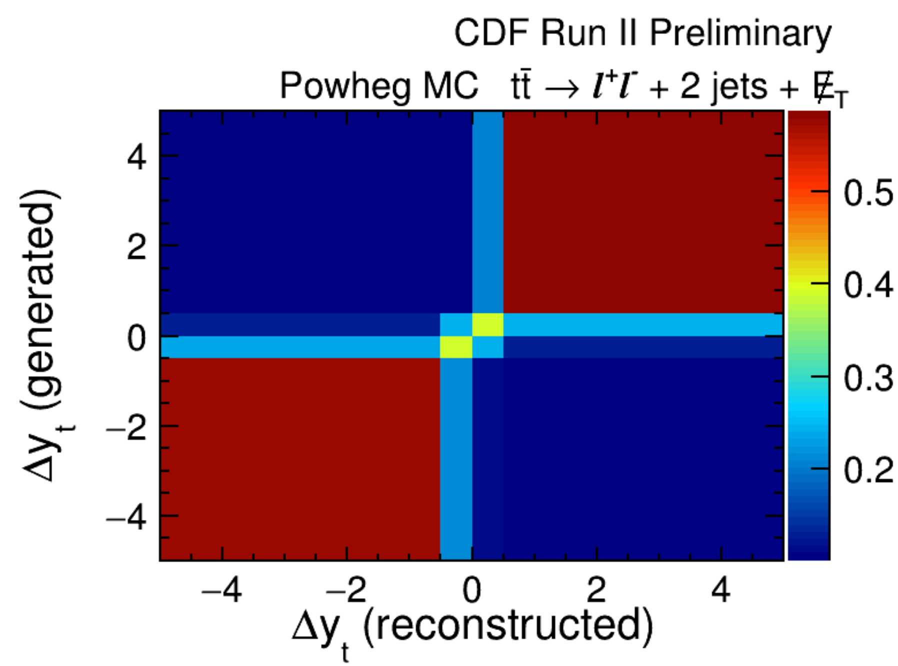
MC and data comparison



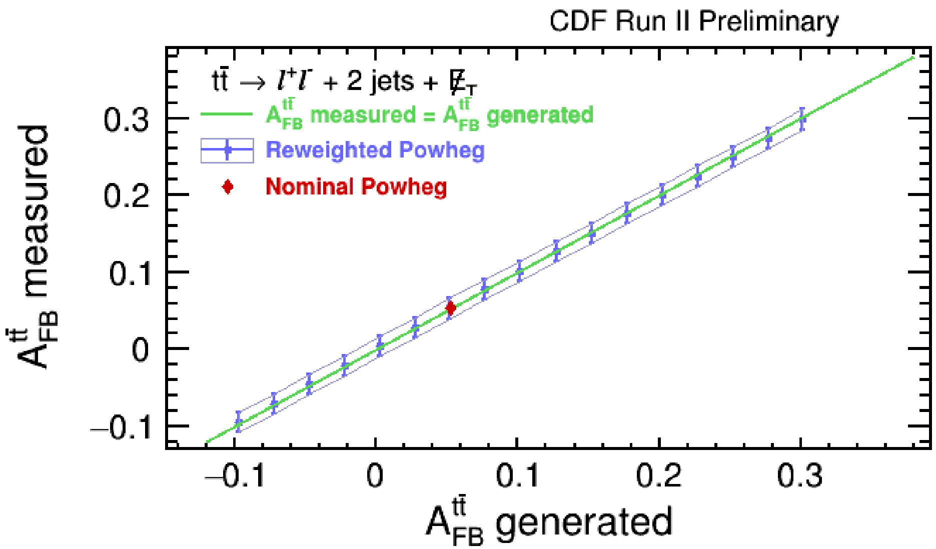


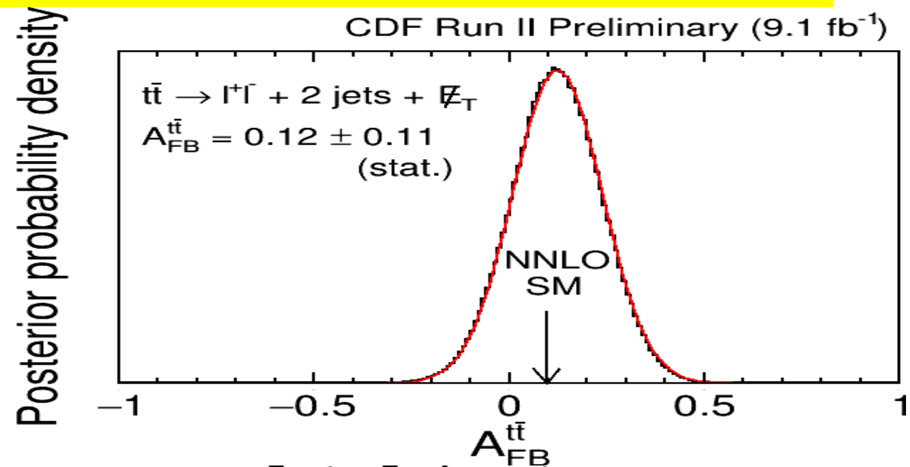


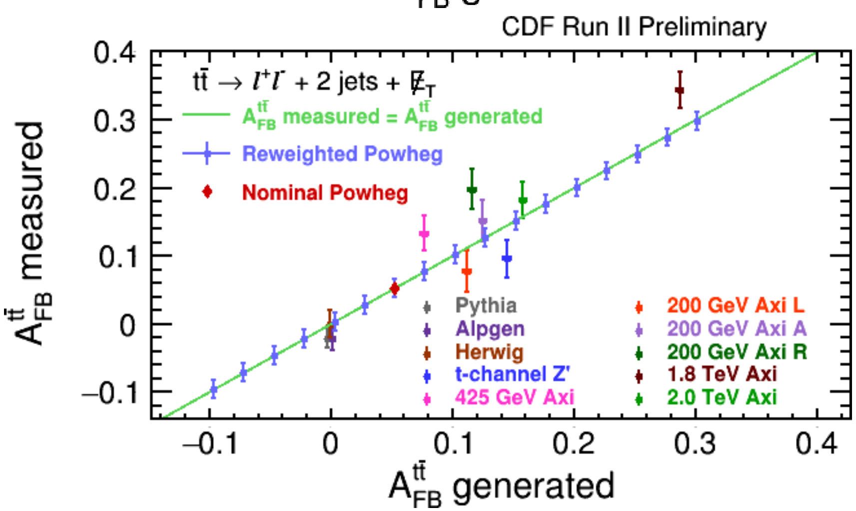


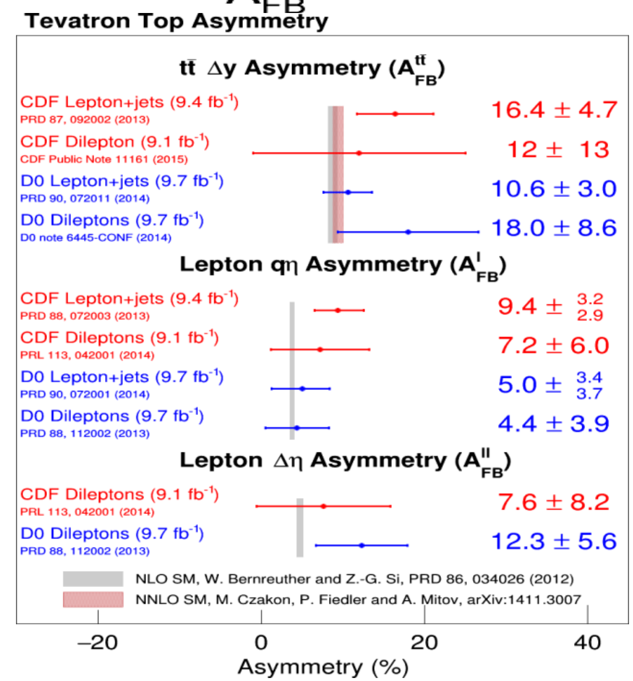


Final A_{FB} in dilepton

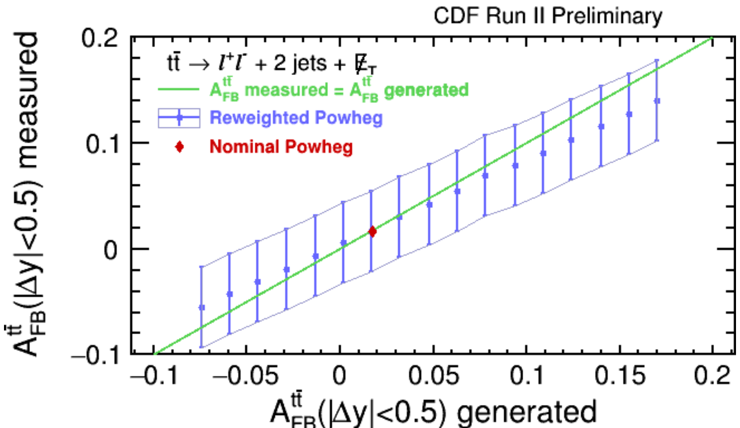


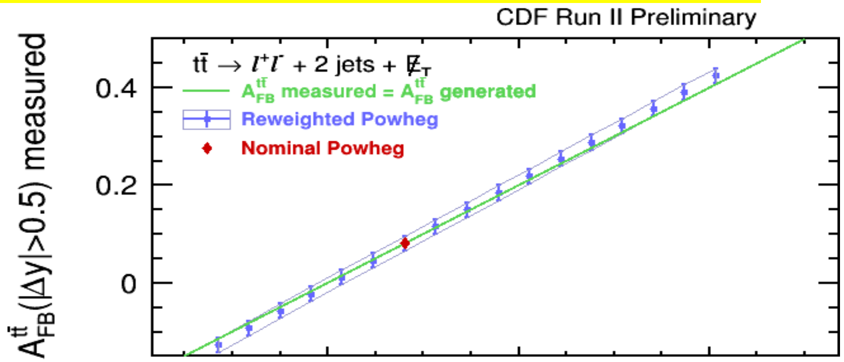


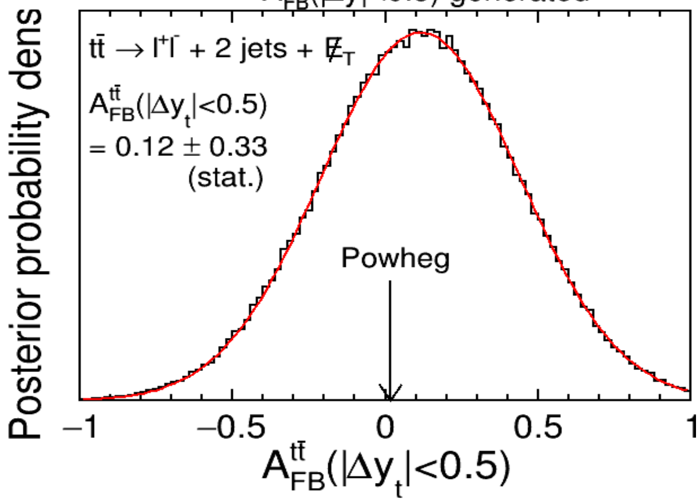


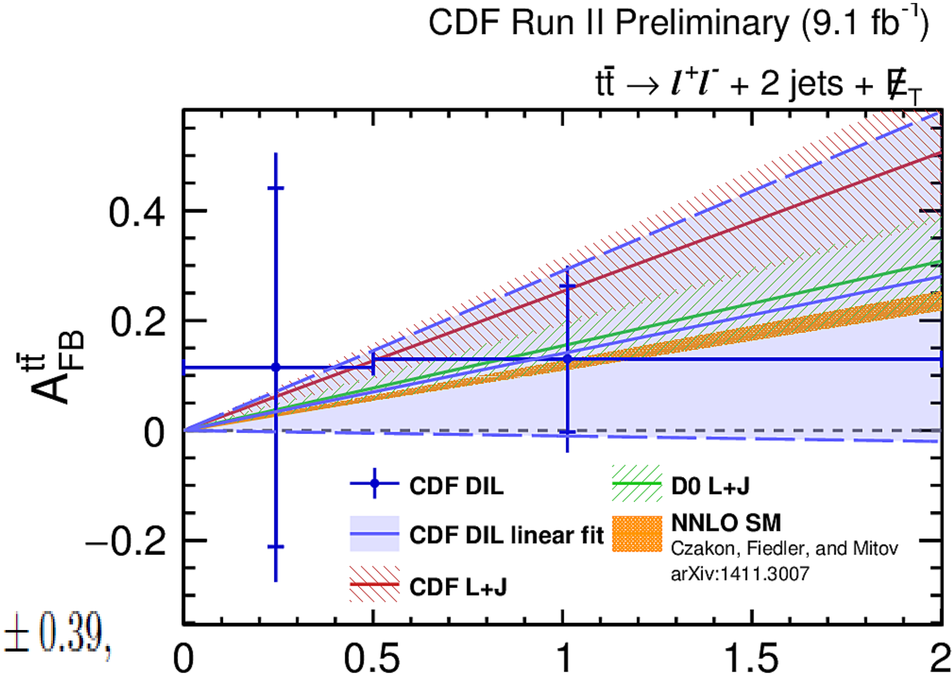


A_{FB} vs Δy_t







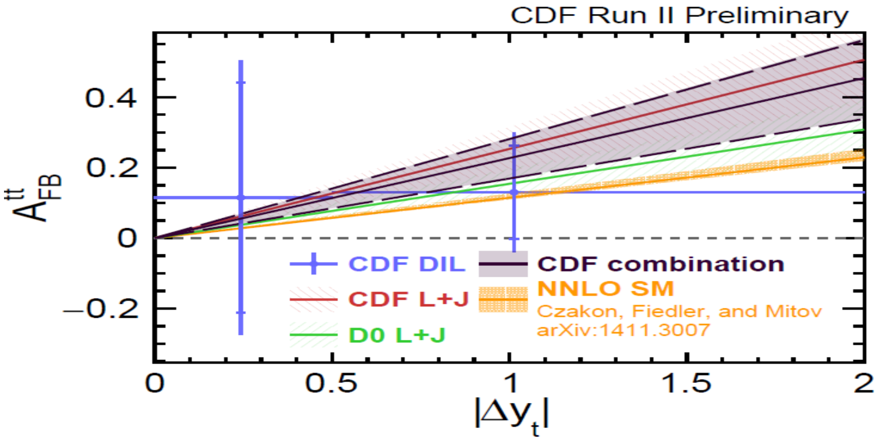


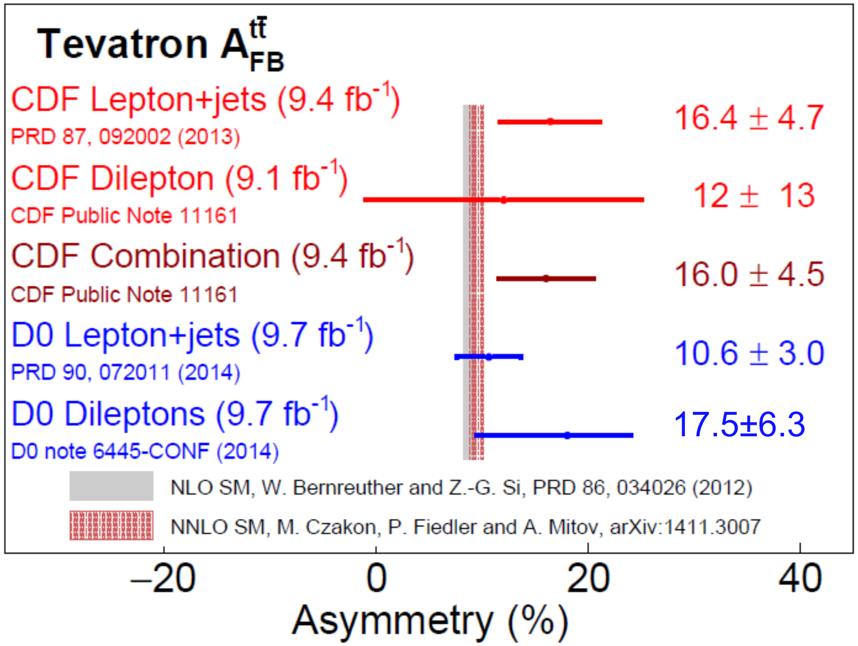
$$A_{FB}^{t\bar{t}}(|\Delta y_t| < 0.5) = 0.12 \pm 0.33(\text{stat.}) \pm 0.20(\text{syst.}) = 0.12 \pm 0.39,$$

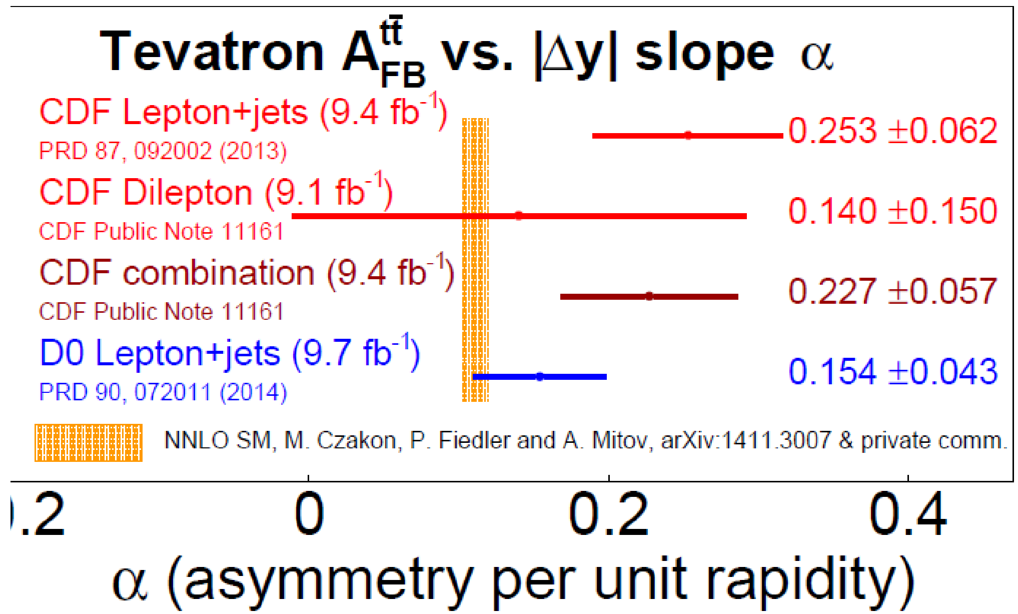
$$A_{FB}^{t\bar{t}}(|\Delta y_t| > 0.5) = 0.13 \pm 0.13(\text{stat.}) \pm 0.11(\text{syst.}) = 0.13 \pm 0.17.$$

Combination

Combine l+jets and ll channels using BLUE A_{FB}=(16.0±4.5)%



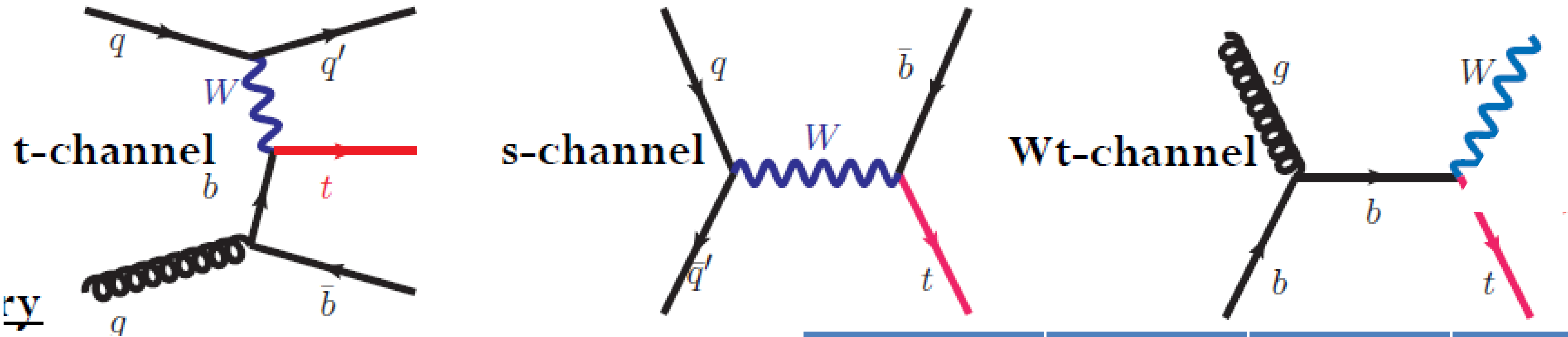




Single-top

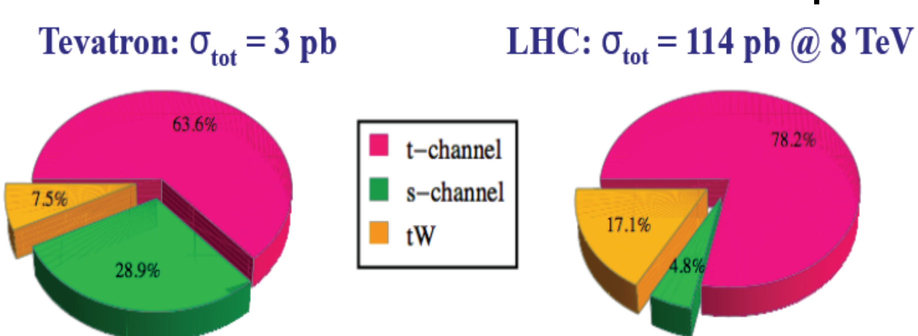
Electroweak production of top quark

- All Feynman diagrams below have a Wtb vertex



x-sec in pb

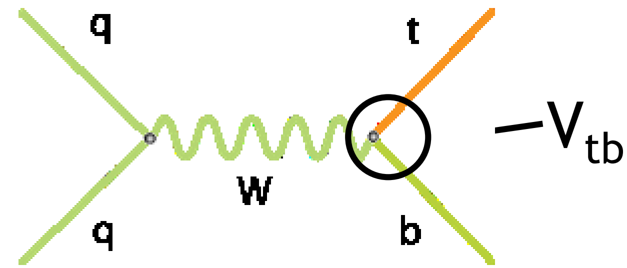
	t	s	Wt
Tevatron	2.26±0.2	1.04±0.1	0.3±0.06
LHC (7 TeV)	64.2±2.4	4.6±0.2	15.7±1.1
LHC (8 TeV)	87.8±3.4	5.6±0.3	22.4±1.5



s-channel difficult at the LHC

Why measure Single Top Production ?

$\sigma_{\text{single top}} \propto |V_{tb}|^2$



Access to the W-t-b vertex

- probe V-A structure
- access to top quark spin

Allows direct measurement of Cabibbo-Kobayashi-Maskawa (CKM) matrix element $|V_{tb}|$:

- Is this Matrix 3x3 ?
  - Is there a 4th generation ?
- Does unitarity hold ?

$$\begin{pmatrix} V_{ud} & V_{us} & V_{ub} & V_{uX}? \\ V_{cd} & V_{cs} & V_{cb} & V_{cX}? \\ V_{td} & V_{ts} & V_{tb} & V_{tX}? \\ V_{Yd}? & V_{Ys}? & V_{Yt}? & V_{YX}? \end{pmatrix}$$

$$|V_{ub}|^2 + |V_{cb}|^2 + |V_{tb}|^2 \stackrel{?}{=} 1$$

Precision electroweak measurements rule out "simple" fourth generation extensions, but see for example:

J. Alwall et. al., "Is $|V_{tb}|\sim 1$?" Eur. Phys. J. C49 791-801 (2007).

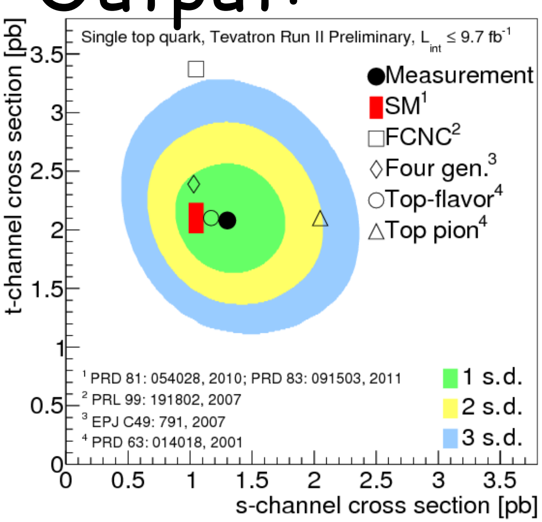
TeV combination

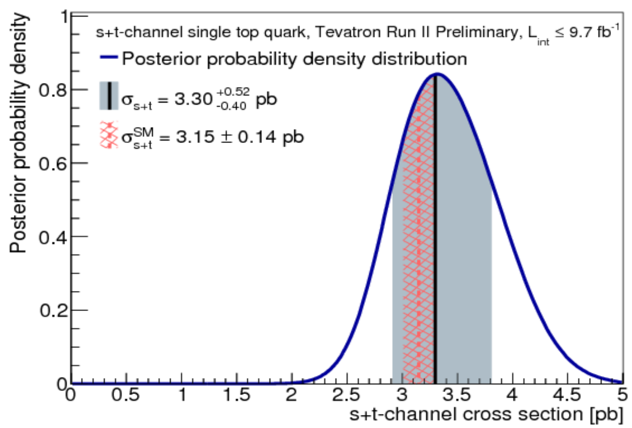
Input:

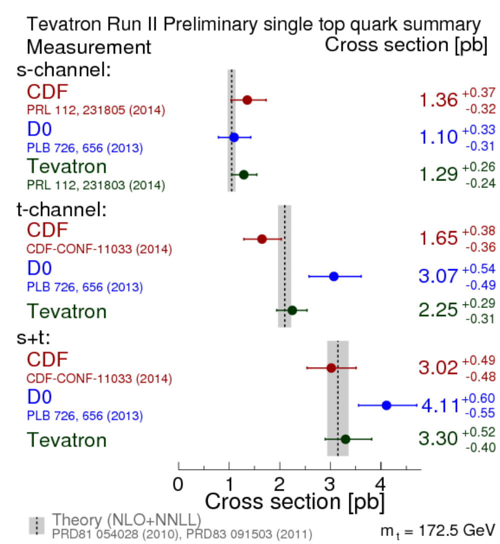
- t, s channel measurement from the two experiments
  - Neglect Wt
- Use discriminants from CDF and D0 performing a likelihood fit to the binned distribution
  - Take into account correlations,

Output:

2d-posterior probability for σ_s, σ_t







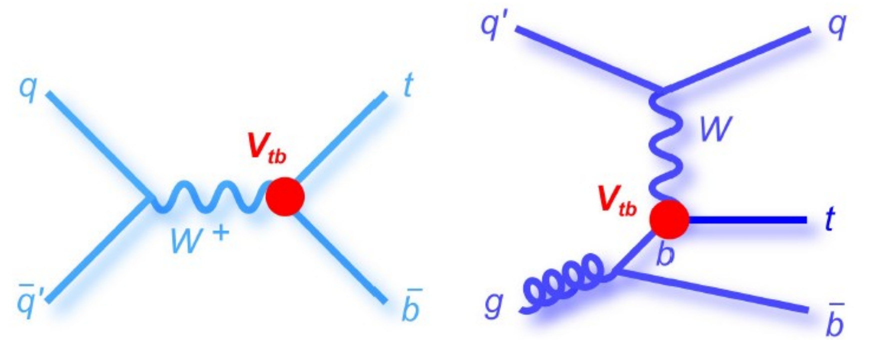
t-channel: $2.25^{+0.29}_{-0.31}$ pb

s+t-channel: $3.30^{+0.52}_{-0.40}$ pb

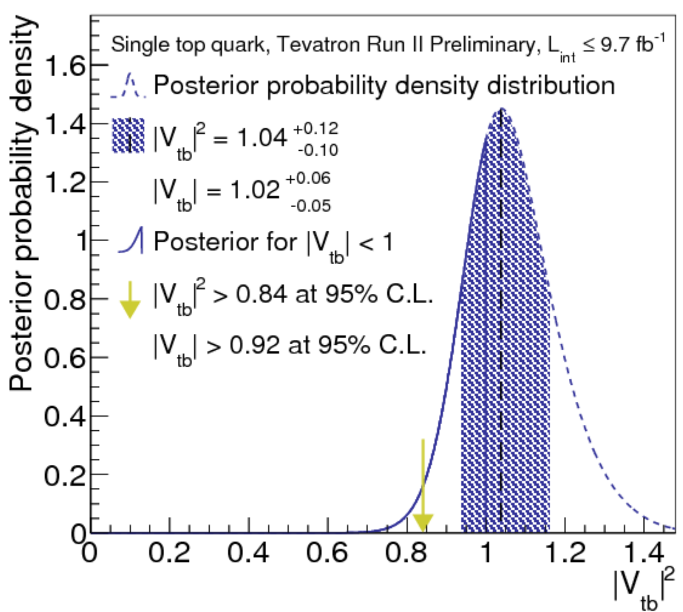
Vtb

Assuming SM top decays the single top (s-channel) cross section is proportional to CKM element $|V_{tb}|^2$

- Therefore no need for other assumptions
- Flat non-negative prior probability



$$|V_{tb}|^2 = |V_{tb}^{SM}|^2 \text{x} \sigma^{obs} / \sigma^{SM}$$



Conclusion

Tevatron was the home of the top-quark

- As such we explored its properties for many years
- We are now coming to a conclusion of our studies

- Some of the excitement derived by previous measurement is, unfortunately, not supported by more studies

Both CDF and D0 are devoted to polish things up in order to avoide leaving any path unexplored